Experimental Stress Analysis

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Lecture No. # 07

Introduction to Shearography, TSA, DIC and Caustics

In the last class we had looked at rudiments of hologram interferometry. There, we pointed out there is a requirement of a reference beam, and also you need double exposure which impose as stringent restriction on vibration isolation. And you should also keep in mind holography is the very sensitive technique, where you talk of displacement measurements of the order of wave lengths. So, even a small disturbance can affect the measurement. Then, we moved on to speckles and we had seen how speckles are formed. We had also looked at, what is objective speckles and what are subjective speckles. And I said in subjective speckle you use a lens, in the case of objective speckles you do not use a lens. And you normally perceive only subjective speckles. Because human eyes have a lens, so when an object is illuminated by laser what you perceive is through a lens. So, it is always subjective. You need to take special efforts to record objective speckle.

Now, what we will do is will go and see what are the speckle methods that we can think of and what are its key features different from hologram interferometry.

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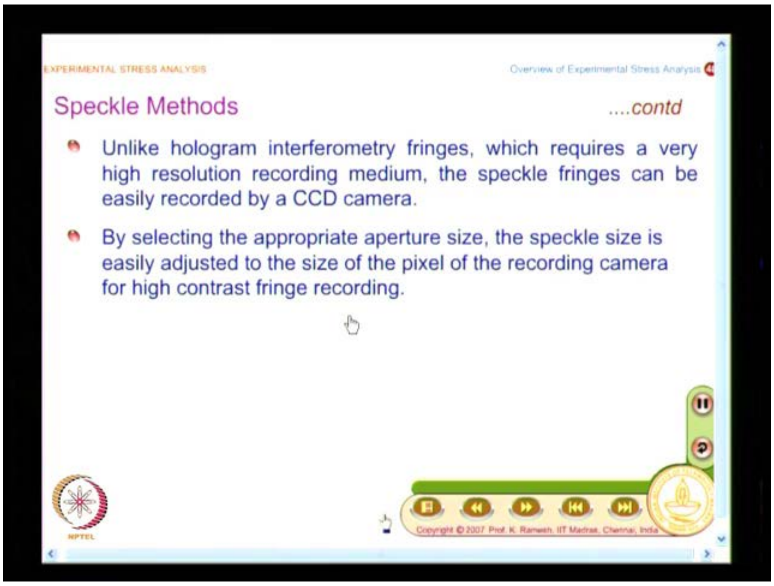

So, for the first thing is, unlike hologram interferometry which requires a very high resolution recording medium, the speckle fringes can be easily recorded by a CCD camera. It is lot more simpler here also you need a good camera for you to do it. And what is done is by selecting the appropriate aperture size, the speckles size is easily adjusted to the size of the pixel of the recording camera for high contrast fringe recording. So, you have a provision by which you can adjust the optical system until you get good fringes in your recording medium you have a provision to do that.

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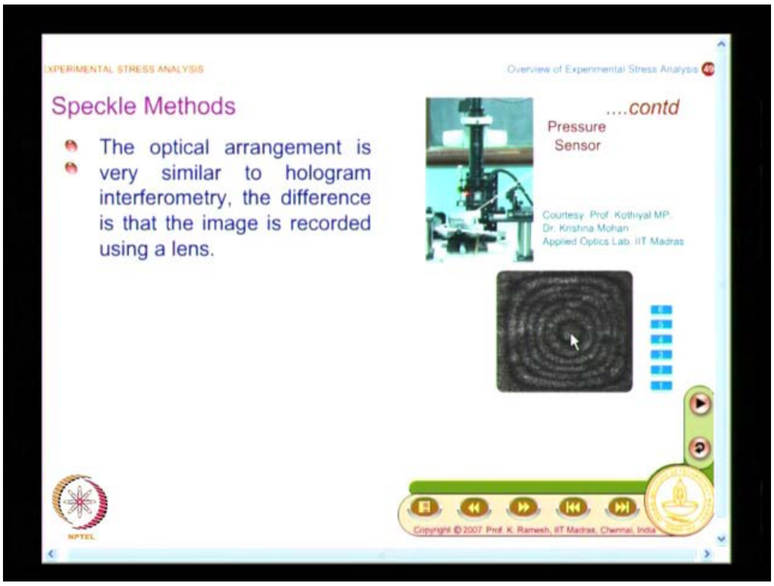

And if you look at speckle interferometry it is again same as hologram interferometry. It is very similar to what is there in hologram interferometry, and we had seen that hologram recording is a lens less photography. Once you come to speckles, we record only subjective speckles, and subjective speckles are recorded by a lens. So, the difference here is the image is recorded using a lens. And you know the example what I have taken here is from a memes application, because we had seen whether it is holography or speckle interferometry, where ideally suited for small scale object measurements.

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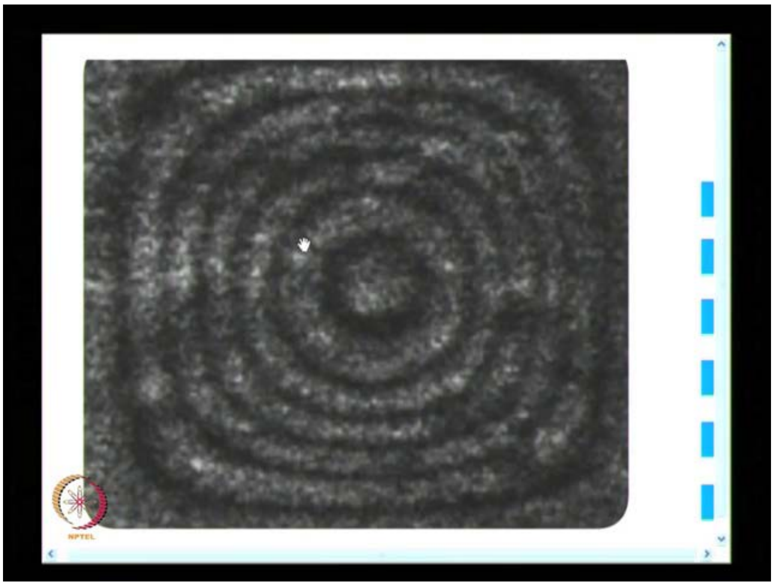

And what you have here is a pressure sensor, and I can change the load here and you can see the fringes, and first impression you get is they have very low contrast, and they are not as more as what you get in photo elasticity. They have specular, you will see dots everywhere and you have collection of dots. So, you have the quiet difficult for you to extract information. So, in all these speckle interferometric methods people spend lot of effort on filtering. Filtering is the very important step in speckle interferometry.

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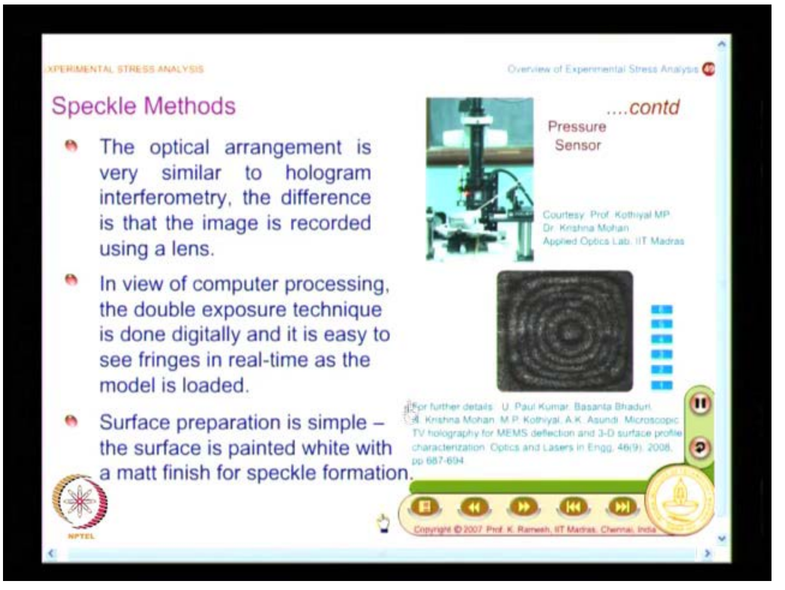

And what you have here is in all these modern techniques they employ computers. Because of computer processing, the double exposure technique is done digitally. So, initially you store be initial configuration in a file and use it for viewing the deformed configuration. And it is easy to see fringes in real time as the model is loaded. So, what you find here is you are able to see fringes in real time that is because of your computer processing of data and you have fast computers to process image information quickly, and it gives a semblance of real time appearance of fringes.

And you know when you want to paste a strain gauge you have to have a elaborate preparation, same is the case when I go for photo elastic coating application. Compare to these methods surface preparation is simple, the surfaces is painted white with a matt finish for speckle formation. You want a specularly reflecting surface. So, you want to have only a simple surface preparation, but even the simple preparation is not simple in the real sense, you need to have some practice on applying your white paint uniformly. It should not have smudges on the surface, when you come to experiments you need to develop skill. The methodology is discuss in comparison to other techniques this method is simple, but even a simple technique requires some kind of a skill development and skill development comes only through practice. You cannot do it on one day, one day you wake up and then you want to go and do speckle interferometric is not possible; you need to have some training and perfect the steps involved in this, then you go and make measurement, your measurements will become reliable. So, simple or difficult is a relative term right.

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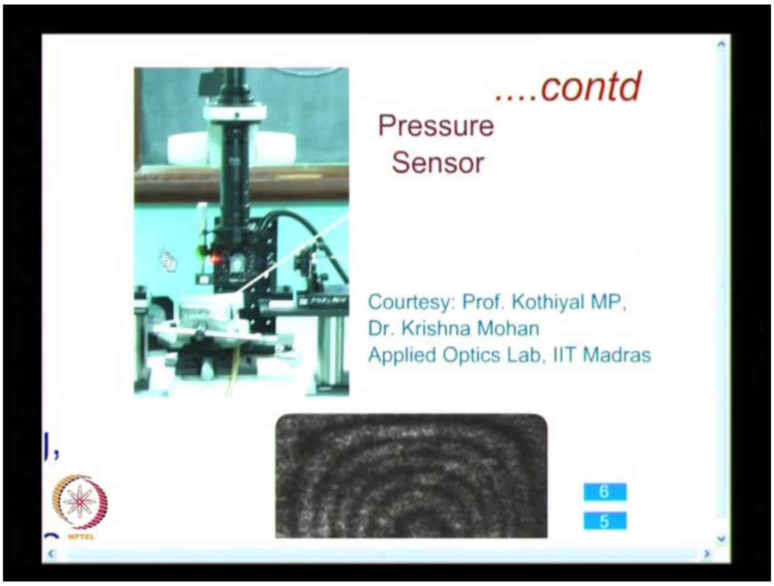

You have to get a uniform thin coating on the surface and we can also have a look at the close up view of this, and this is actually a microscope which is used, and you have a pressure sensor which is very, very small, and you see the fringe pattern of this, and this was done in Professor Kothiyal's lab, applied optics lab, IIT madras. And which you want to have further details you can go to this reference, and you know there is always a discussion in academic circles whether to label a method as speckle interferometry or holography. This debate is one they have called it as TV holography here, 3-D surface profile characterization and so on. So, this debate is always on.

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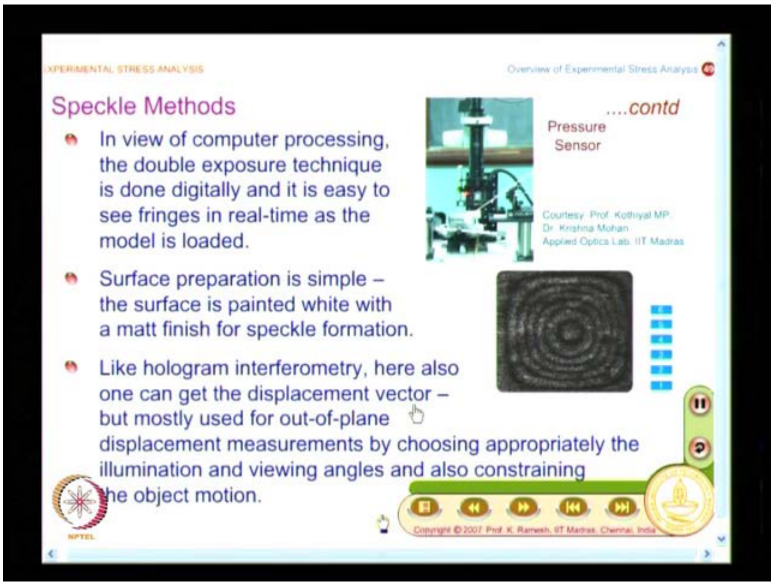

And in speckle interferometry also you can get the displacement vector. And I had mentioned earlier when you get a displacement vector interpretation becomes little more complex. And you need to have methods and if you go to this literature they will talk of something like sensitivity vector and how to extract data these are all mathematical details. We are not getting in to those mathematical details at this stage. Our focus is mainly to appreciate the principles involved in various techniques and also look at broadly for which class of problem these techniques are applicable, and also limitations broadly speaking what way these techniques look and how these can be compared; some kind of information which will aid you to arrive at appropriate technique for the given application.

So, what you find here is mostly you will get out of plane displacement measurements, but you can get the displacement vector by choosing appropriately the illumination viewing angles and also constraining the object motion. This is common to both hologram interferometry and speckle interferometry. We want to get u and v displacement, and you have to choose the illumination, viewing angles and also constraining the object motion all these have to be used for finding out specific components of displacements. On the other hand moiré by choosing the grating your interpretation becomes simple. Here it is involved, because you collect more information and so you have to be systematic in filtering out what is in that you need.

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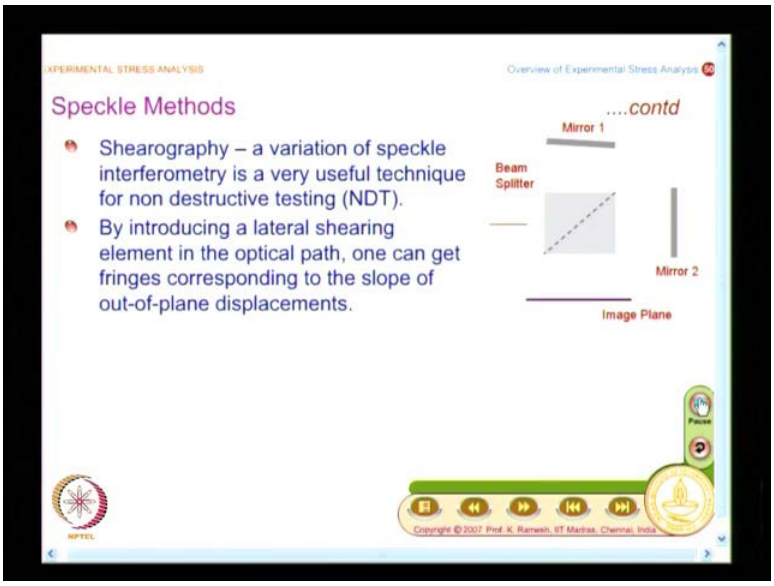

And another popular version of speckle interferometry is shearography, and this is a very useful technique for non destructive testing. In fact, for honeycomb panels, this is the very popular technique with composites becoming very important structural materials; where again you have problem of delamination and techniques like this go a long way in identifying. And this shows a shearing element will have a closer look of it.

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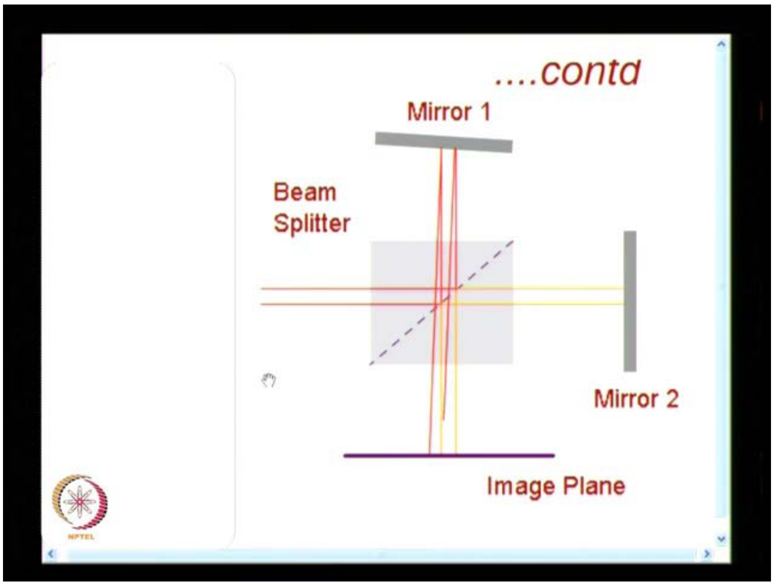

So, what I have is I have a beam splitter. One ray goes straight and hit this mirror and comes back, the other ray goes there, and get sheared and on the image plane you have for one incident ray two rays are seen. Same thing we can watch it for the second ray. So, I get one ray from the mirror two and I get another ray from mirror one. You make a sketch of it I will do the animin repeat the animation again for you to understand how you perceive this. And because of the shearing action you essentially measure this slope. You measure the slope essentially. So, you have the ray goes and hits its mirror, this is kept perpendicular and the mirror one is slightly tilted. So, beam splitter sends one ray to this mirror and sends other component to this, and whatever comes from this because of the tilde it gets shifted, and this is called it is also said it is shear to this point. So, for each incident ray, you will have two rays impinging on the image plane. And we will just have a look at the animation again.

And this is what you see here, I have the ray goes straight and hits this mirror. Another component goes to mirror one and this gets shear. And in shearography, the vibration isolation requirements are less stringent that is why it is become a very popular technique in an industry. And many manufactures of giving out shearographic equipment. It is used routinely for non destructive testing of several composite panels, honeycomb panels and so on.

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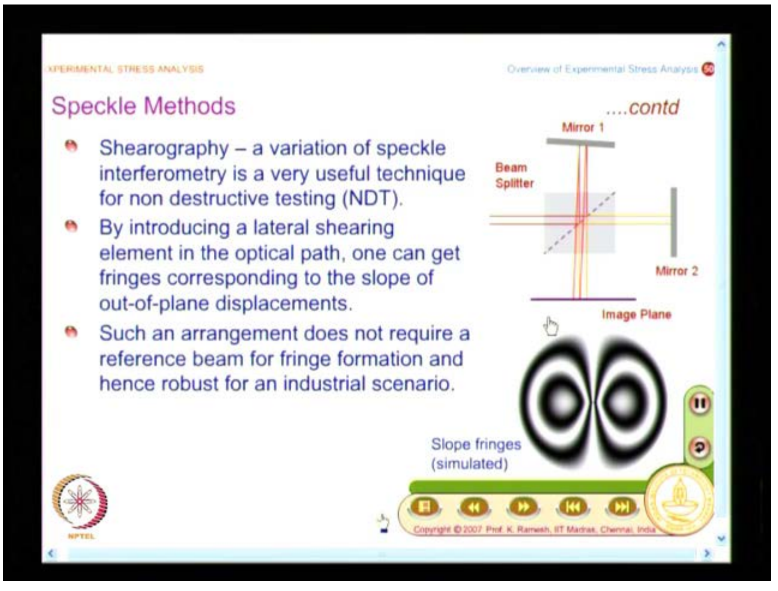

And when you do this what you get, you get essentially slope fringes and we also noted that these are butterfly fringes, because of the shake, because on the shop floor they would like to classify this as butterfly fringes for easy identification. In fact, it is dou w by dou x contours. So, what we find here is by introducing a lateral shearing element in the optical path, one can get fringes corresponding to the slope of out-of-plane displacements that is what you get here. And this, there is nothing like one is a reference for the other, other the is reference for this and nothing like a single reference beam for fringe formation and hence robust for an industrial scenario.

So, what you find here is shearography is a robust technique compare to speckle interferometry or hologram interferometry. If you put a shading element it makes your life lot more simpler. And you get (( )) information, you get only a slope information you do not get out of plane displacement. So that is the difference. It makes your experiment simpler at the same time gives your different type of information. So, we have so for seen quite a few techniques; what is a physical principle and what is the essential difference between them.

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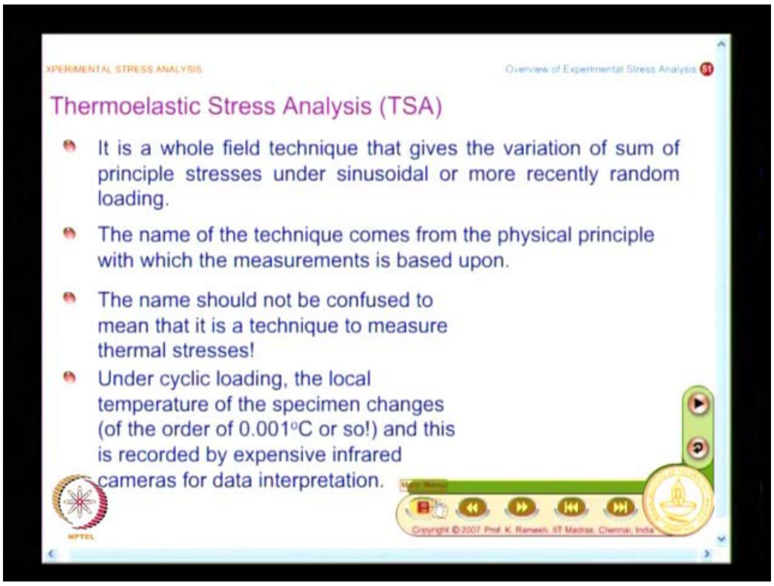

Now, we move on to another experimental technique which is again a whole field technique which is known as thermoelastic stress analysis. It is a whole field technique and it gives the variation of sum of principle stresses under sinusoidal or more recently random loading, because if we look at the history initially it was developed for sinusoidal loading. Once the technique has mature people are found methodology to extract data even for random loading situations. And it does not give sigma 1 plus sigma 2, it gives variation of sigma 1 plus sigma 2 that is a difference. So, you have to have a cyclical loading on the object and you find out what happens, and here again you are a employing a physics, we will see what is the physics behind this technique.

And the name of the technique comes from the physical principle; one common danger is thermoelastic, if I want to find out stresses due to thermal loading you can directly use the technique; there is a misnomer, you cannot do it like that depends on the principle on which it is based upon. So, that is what is mentioned here the name should not be confused to mean that it is a technique to measure thermal stresses; it is not so. What the physical principle is, under cyclic loading, the local temperature of the specimen changes and this change is very small, you cannot go and touch and feel it, which of the order of 0.001 degree centigrade or so, so very small measurement from temperature point of view. And this is recorded by expensive infrared cameras for data interpretation.

So, people have identify and see as technology as advanced, we are able to measure even small changes in temperature. People identify the small changes in temperature takes place and this is exploited to reveal information of the stress field and it gives a particular kind of stress field, and it was originally develop for high temperature application, because you cannot go near and then make any measurement and people wanted to have non-contact measurement and they want to have a technique which could work at high temperatures particular for gas turbines when they work at high temperature they want to make measurement. And what you find here is the temperature change is very small, we have also looked at while we looked at strain gauges. We were talking of micro strain and that is 10 power minus 6, you are looking at 10 power minus 6 of change in resistance or change in the strain. When you come to temperature were able to go only to the order of 10 power minus 3, but even this is very, very small.

And if you look at moiré or if you look at photo elasticity or you hologram interferometry, you see the fringe contours, after processing you see the fringe contours. In a technique like this you do not see fringe contours as such; it is all plotted from the infrared camera result post processed that is why you get the result. Here the technique is also slightly different you have to do post processing for you to look at the kind of information that you have recorded.

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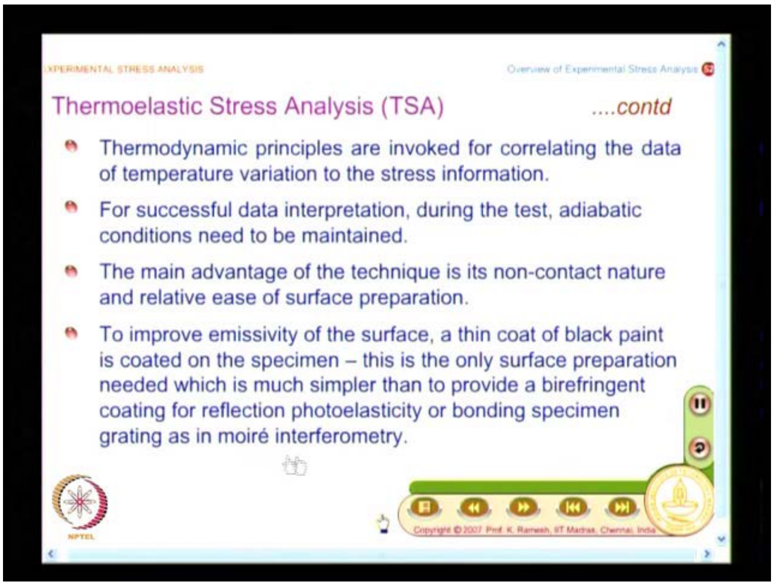

And another important aspect here is you use thermodynamical principle for data interpretation. So, as you go advanced you also have more complicated mathematical development for you to interpret experimental data. And you have be very careful in conducting the experimental method, you should be worried about other thermal sources, you should suppress those information, because you are essentially recording emissivity of the surface whatever the emissive characteristics. And if you have other sources of thermal disturbance they have to be suppressed. So, the experiment has to be conducted very carefully. And you need to maintain adiabatic conditions for successful data interpretation. And this adiabatic condition comes in the form of what is this frequency of loading. There is a recommendation, what is a minimum frequency of loading you have to maintain. So, you have to look at this, so the requirement of adiabatic conditions imposes certain restrictions on how you do the experiment.

And the main advantage here is the technique is non-contact. And again you know when there is a small advantage you should take note of it. It has a relative ease of surface preparation, it is again a relative term. And here what is the kind of surface preparation you do? You have to improve the emissivity of the surface, a thin coat of black paint is coated on the specimen. It is not white paint like in speckles, but it is the thin coat of black paint. And again it is a comparison that is what is summarized here. This is the only surface preparation needed which is much simpler than to provide birefringent coating for reflection photoelasticity or bonding specimen grating as in moiré interferometry so on and so forth. We can sight many such comparisons that is not something difficult. So, what you find here is you have to apply a thin coat of black paint and as I have said earlier even to get a thin uniform coat you need to develop skill. Though it is simply said it is a comparatively less difficult.

But even this you will have do a with care; unless you do it with care you will not be able to do it; you will not be able to get reliable experimental results. And people have combine thermoelastic stress analysis with photoelasticity and try to find out stress separation and all those exercises have done. And it is (( )) that you have a look at what is the measurement scheme employed here.

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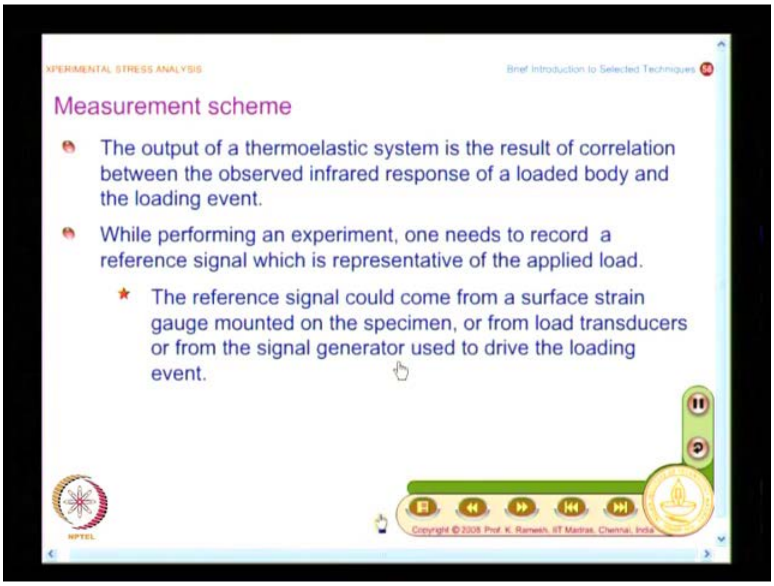

I will give an idea how you go about and what do you do is as I said you do not see the information directly; the output of a thermoelastic system is the result of correlation between observed infrared response of a loaded body and the loading event. So, you have to make a correlation and you have do post processing of it, then displays the result. So, I need a signal to a record how the body is loaded. So, you need a reference signal. So, while performing an experiment, one needs to record a reference signal which is representative of the applied load. This is done this can be done in various ways that is what is listed below.

And what I find here is the reference signal could come from a surface strain gauge mounted on the specimen, or from load transducers or from the signal generator used to drive the loading event. So, what I need is I need a reference signal; I need to have a correlation between the loading event and the recording phenomena. So, for recording the loading event we need a reference signal that could come from a surface strain gauge or that could come from a load transducers or from the signal generator. This idea would become clear if you have a look at how the whole arrangement is may ready for a thermoelastic measurement that we will see immediately.

I will be in able to write write down this, you know since all these statements are available on a readymade platform as I am not going and writing. You may have to take abbreviated information of this rather than long sentences; you may write it do that when you want to take down the notes. I will also try to go as slowly as possible. So that you have ample time to record this information. And what we will see is these ideas will become clear if you look at how a thermoelastic test is done. This is depicted in the line sketch here.

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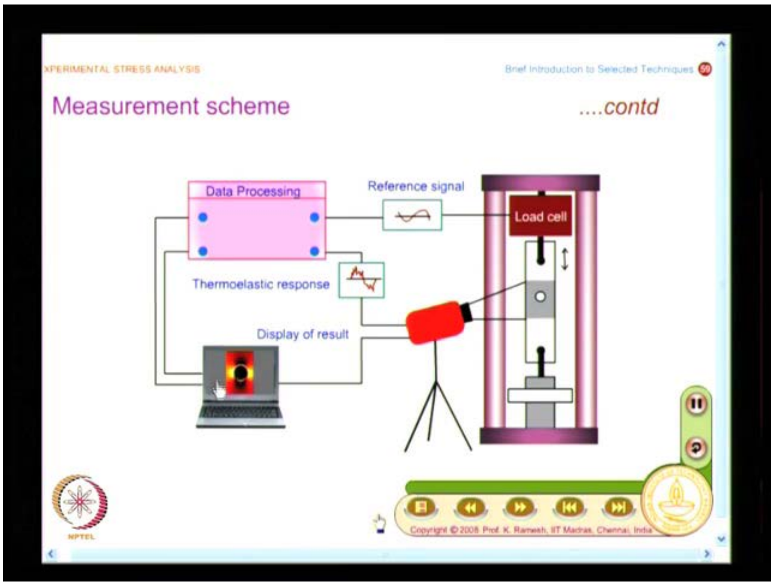

And levels look at part by part. I will also give you sufficient time for you to take down this sketch. You make your sketches little brief, you will not have to put these pillars with lot of effort minimize that. The essence here is I have a specimen the region of interest is painted black and this arrow shows that I am applying a cyclical loading, I do up and down, I do a cyclical loading. So, the model is subjected to a cyclical loading.

And this event is recorded by a thermoelastic camera and mind you thermoelastic cameras are very expensive, it is not like visual range cameras in a thermoelastic even the lens is very, very expensive, and the other restriction is you need to have better cooling systems for you to cool down the thermoelastic camera, because the temperature generated because of that can give Fourier signal. In fact, they have a specific engines for cooling this camera, you have certain cycles are used for cool this camera. So, what I have is I have a specimen mounted on a loading frame which is cyclically loaded and the region of interest is painted black, and you have a thermoelastic camera which focuses on this. And you get a response from the thermoelastic camera. It could be a response something like this.

And from the load cell of the testing equipment, you also get a reference signal. So, what you need to do is in thermoelastic stress analysis, you need a reference signal how the system is loaded. You want to correlate whatever the results that you get with respect to a reference signal. The camera by itself does not give you any information for you to visually look at. So, it has to be post processed and then display appropriate. So, what I have is I have a data processing unit which takes the reference signal, and which gives you the output once you take it to the computer, you could display this result in a fashion which is convenient for you to interpret. So, what elements you have, you have a loading system, you have a thermoelastic camera and this is taken to the data processing unit, you also have a reference signal and you post process this data and display the result. So, you have a plate with the hole with sigma 1 plus sigma 2 contours. They appear like this.

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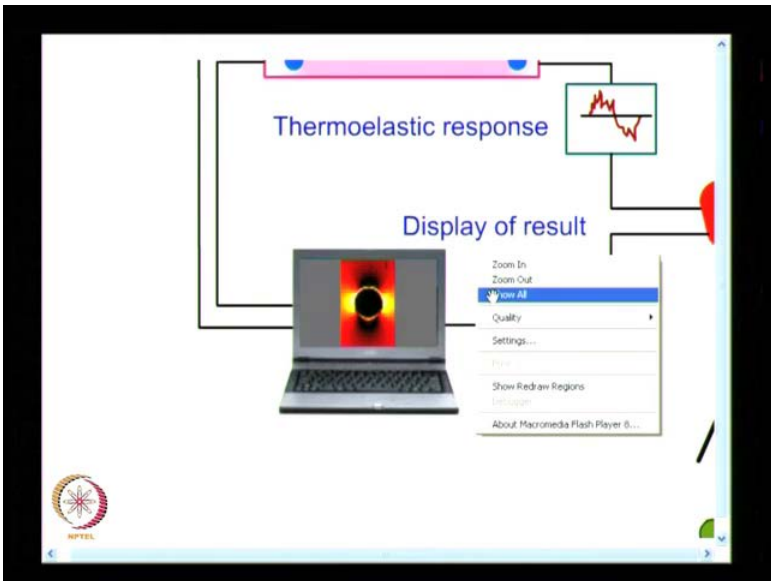

We can also have a larger picture of this. This is how you have the a display and it is the post processed display. And this is the case when you go to the next technique, here again you do not see the fringe patterns visually. You only you have to post process the data and displayed in a fashion convenient for you to understand. So, what you find here is more and more computers are used in experiments that becomes evident in some of these sophisticated techniques, and if you go and look at the price it is (( )) cost, because of the thermoelastic camera and also the whatever the lens system that is used, and if you look at the resolution not as comparable to as what you get from a visual range optical system. It is in operating and infra red regime, so very expensive. So, unless you have very high level of funding, you would not be able to do a test of thermoelastic stress analysis.

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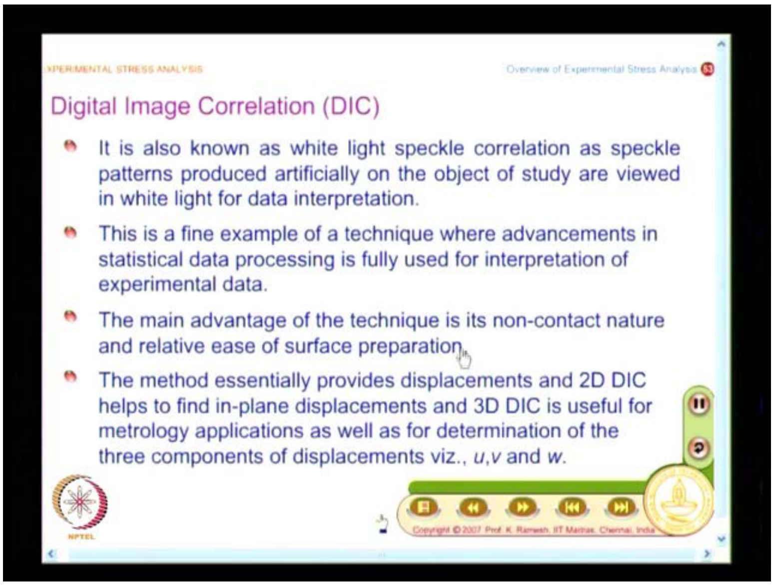

And the next technique what we will go and look at is one of the very new and emerging technique called Digital Image Correlation. You know the name itself is very interesting it is the image correlation; we have seen in the previous methodology, there is also some other type of correlation was taking place between the reference signal and your thermoelastic response. And this uses speckles and these are called white light speckle. In the speckle method, what we did was we had a laser beam impinging of the model, and you had speckles develop naturally, it was not artificially created. If you have a specularly reflecting surface, you had speckles, because of laser illumination and that was used for all the measurement. And this is the offshoot of that kind of an approach.

Here you have this speckles arbitrarily done; you have the speckle arbitrarily done. It is done externally on the specimen under consideration, artificially it is done, and you use white light for data interpretation. So, you can really cover large areas comfortably. And you have to look at this is the fine example of a technique where advancements in statistical data processing is fully used for interpretation of experimental data. So, it is more of I always tell that is more of computer processing and less of seen the joy of looking at fringe patterns in real time; you will not see fringe patterns real time in this. You will only see dots speckles on the surface, they have to be post processed and they have to be plotted in a fashion convenient for you to interpret. But this is becoming a very, very important technique, because of development of newer materials. There are certain materials you will not be able to do experiments otherwise.

And as again, this is an optical technique. All optical techniques are buy and launch non-contact in nature. And here again you know you do not need a complicated surface preparation, but I should caution the speckle formation is not simple. You have to have randomness, you have to have particular characteristics and formation of speckles again you have to develop skill and size of the speckle matters, because you can do for multi scale analysis depending on the scale on which you operate, you need to have that correct size of the speckle. So, though it said surface preparation simple in relation to strain gauge where you will have several steps for surface preparation. Compare to that here you have only put the speckle by a spray gun, but that requires again skill.

And what is the information it gives; it provides displacement, you have 2D DIC which helps to find in-plane displacements and you also have three-dimensional DIC which is useful for metrology applications as well as for determination of the three components of displacements; u, v and w. So, this is the your directly getting displacement information. And it uses quite a bit of data processing which is not seen in other experimental techniques. Here more of number fringing is done, and when you go to 3D DIC you have (( )) images recorded with two cameras, calibration is very, very intensive and people have developed proprietary software how to the calibration. So, the technique is emerging that is the way you have to look at it.

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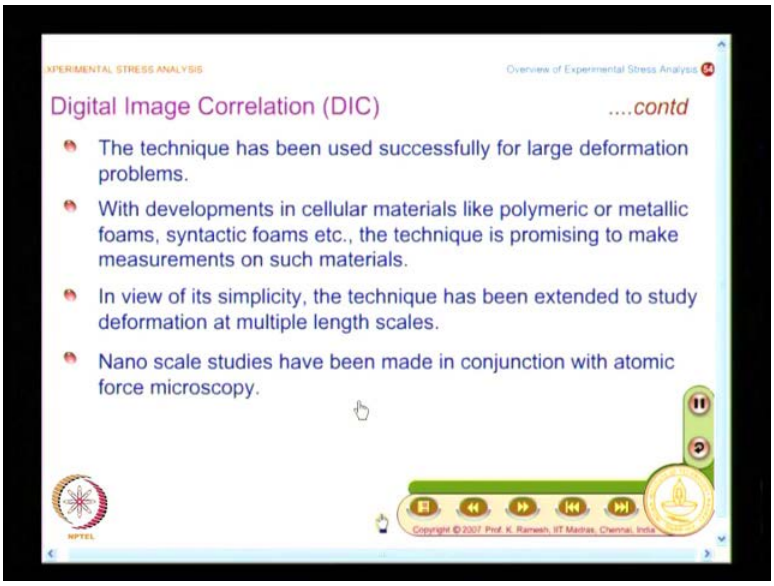

And what I have here is for large deformation problems the technique has been used successfully that is how people start we have seen when we looked at moiré, people had grid methods and then from the grid method they graduated to having the grid, put a circle inside, look at the stress direction, then they refined it by putting two grids one over the other that is why moiré was developed. And then if I am geometric moiré, they graduated to moiré interferometry, where they could go for finer and finer displacements. And digital image correlation as successfully applied for large deformation problems. And these days we do encounter in our design large deformation being allowed, and so you need to have techniques which do this.

And you also have several new materials cellular materials like polymeric or metallic foams in automobile manufacture they want to put metallic foam in your structure, so that it absorbs energy when you have a collision. See in earlier days and stream engines were developed, 15 kilometers per hour was considered terrific. Now, you travel at 350 kilometers per hour. And when you increase the speed any collision becomes dangerous. So, you need to have productive mechanism for you to have a and people all thinking of using metallic foams, syntactic foams and all this materials are very peculiar even to find out the material property they cannot be a conventional test and they depend on digital image correlation to find out even the material property.

So, the development of new material, a force also the development of newer techniques for data gathering and interpretation; and the technique is very simple, if you go from one scale to another scale the methodology is essentially same only thing is your optics has to be sensitive enough and your speckle size should be adjusted suitably. In view of that the technique has been extended to study deformation at multiple length scales.

You know could today is the… I mean these days we talk of nano mechanics. So, nano scale studies have been made in conjunction with atomic force microscopy, where you have a whatever the beam that we used inside, if you want to make measurement, people have used digital image correlation and we are able to do even nano scale studies. Holography is also applied for nano scale studies. So, the advantage here is once you have the software developed for image correlation by varying the size of the speckle and also your optical arrangement, it is possible for you to go to smaller and smaller scales or even large scales. People also use image correlation for finding out the buckling behavior of wind mills, you have huge wind mills; now renewable sources of energy people are paying attention, you have very large wind mills have come and for that those blades are sensitive for buckling, and you have a very large area, and you need to find out the buckling whether buckling takes place or not and people use image correlation.

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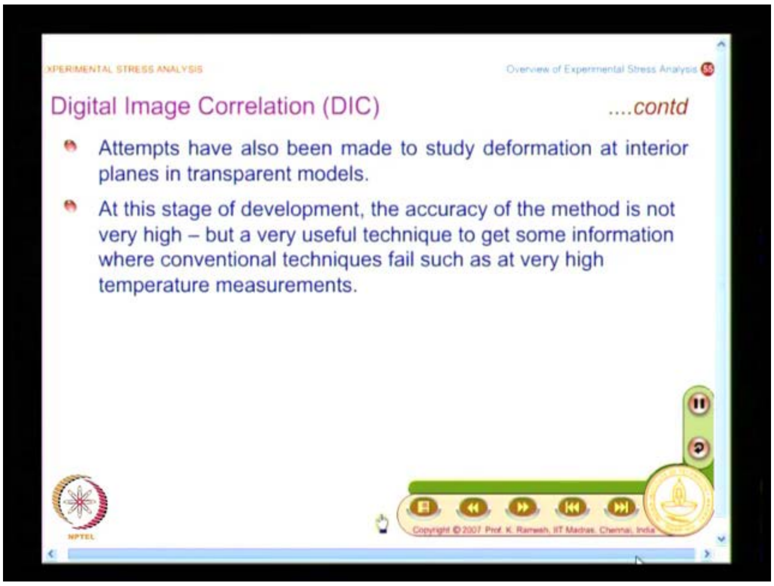

And being an optical technique they also find out how to find out information at interior planes in transparent models. And you should also accept at this stage of development, the accuracy of the method is not very high. So, that is the scope for research. So, if the accuracy is not high; this is the ideal area where people can refine; it is a very useful technique to get some information where conventional techniques fail such as at very high temperature measurements. People have done, people have done at very high temperature whatever is the particularly when you are looking at re-entry vehicle systems, in space technology they look at re-entry vehicle system, they all subject to very high temperatures. And unit has some measurement and people have attempted using image correlation, because of non-contact nature and they have been able to get useful information for the design. And if time permits we make spend little more time on image correlation - the main body of the course.

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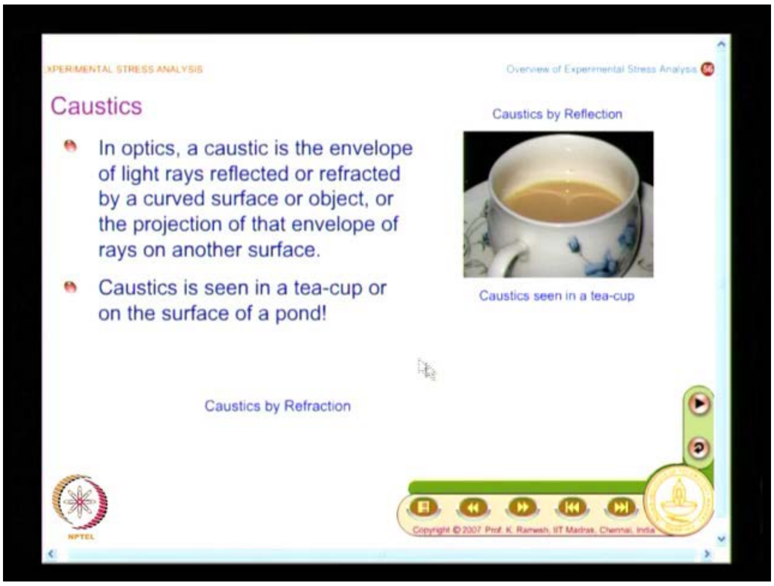

Now, we move on to another interesting optical technique which is the method of caustics. And what I want to mention here is caustic is the envelope of light rays reflected that is what you have seen earlier in the beginning of the course. It can also be refracted by a curved surface or object, or the projection of that envelope of rays on another surface.

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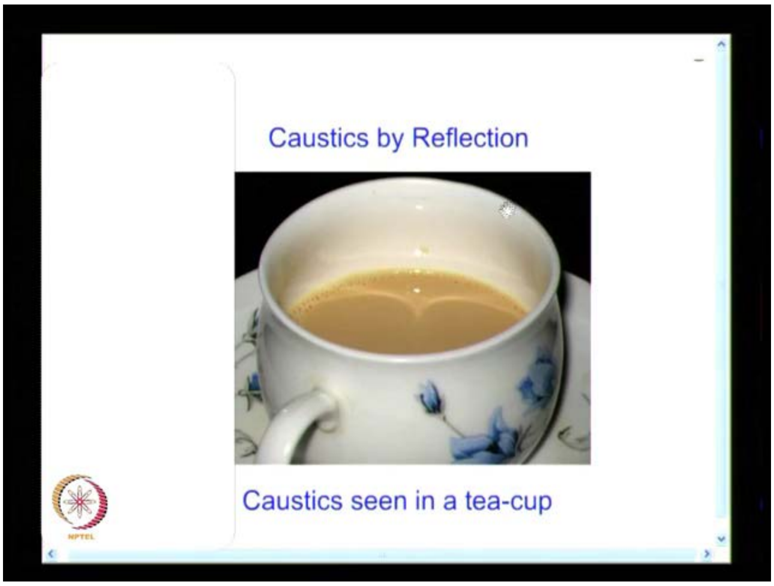

So, what you see here is, I have a caustic by reflection, I have a tea cup, and because of this curved nature and with appropriate lighting, light hits on this curved surface and gets reinforce and you see a silver line as a (( )). This is by whatever the line that you get, the principle is called caustics. The same name is also given to the optical technique; we use it for measuring high stress variant problems. But this is the physical principle.

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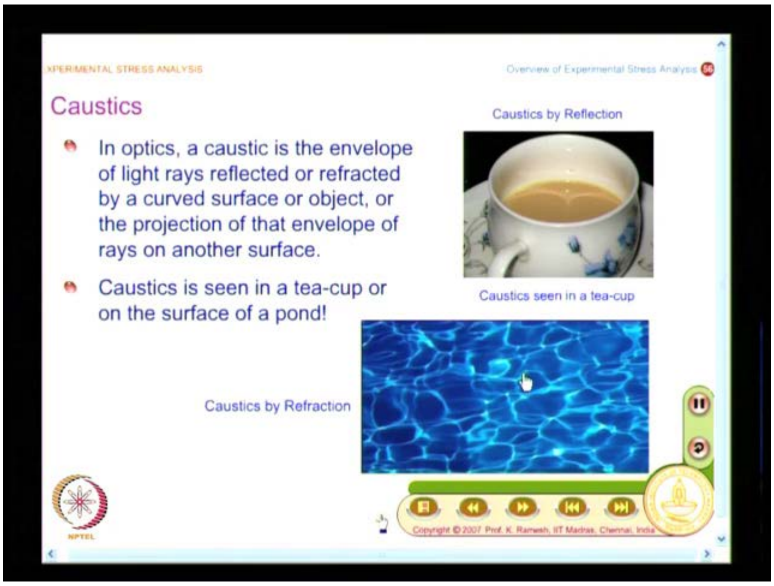

And when you go to a pond you may also see a nice structures like this and all these silver lines what you see then, they are all because of the phenomenon of caustics. Now, you can go and see you might have noticed it, but you may not have named it; now, you can go and see these are all nothing but caustics. So, caustics is seen in a tea cup or on the surface of a pond. What is its use for me in stress analysis? See if I have to use even there is join looking at all these patterns and name them as caustics, but I must also have its utility from the stress analysis point of view; how it is seen; we will have a look at it, we will also elaborate up on it.

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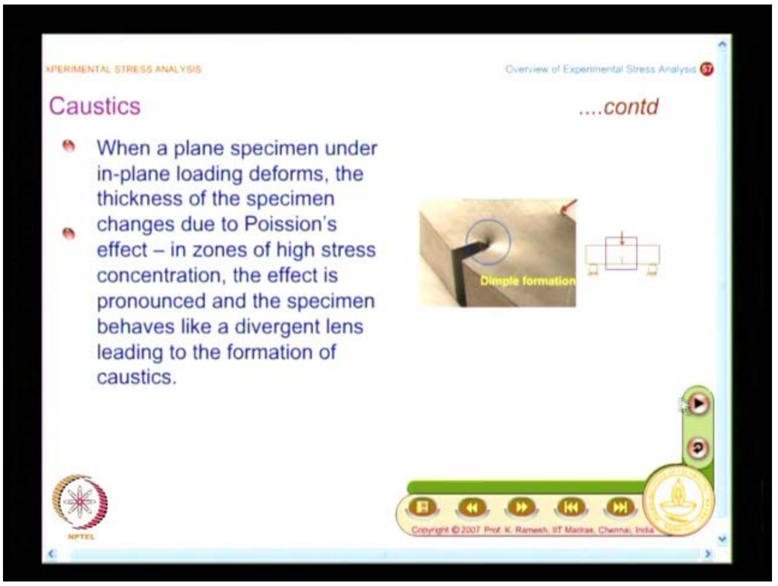

First we look at the what is the principle, and this is what is shown here, I have a aluminum specimen which has a crack and you see a dimple formation here. First we will see this then look at the reason behind it.

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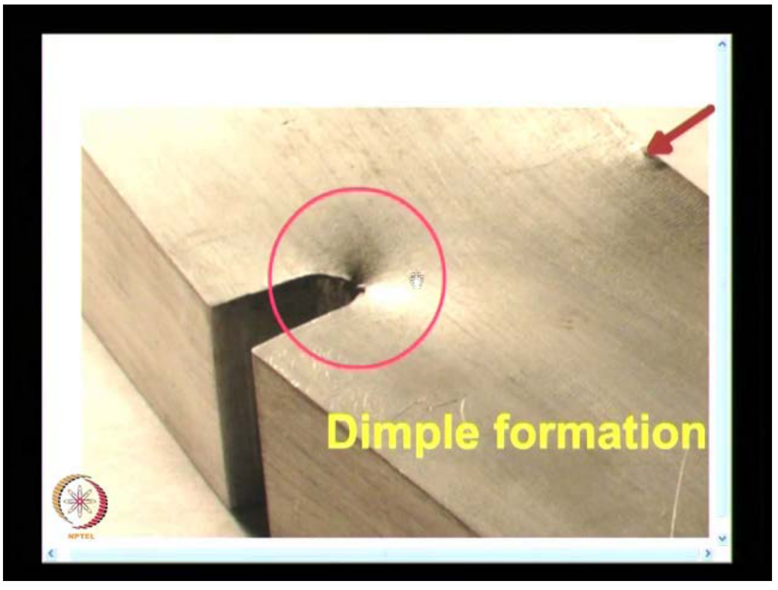

Can you see the dimple very clearly at the tip of the crack, you use see a very large deformation here, and this occurs when I apply load. When I this is in three point bending, when I apply the load I have a dimple formation. So, what you find here is when a plane specimen under in plane loading deforms, the thickness of the specimen changes due to Poison's effect. If I do not have a crack, I would not see the change in the thickness very prominently. Because of the crack which is the high introduces high stress concentration, the change and thickness is also very significant and that is seen as a dimple.

So, in this is particularly seen in zones of high stress concentration, the effect is pronounced and when you look at here when I send the collimated beam of light I can have a transmission arrangement as well as the reflection arrangement. If I have a transparent model then it behaves like a divergent lens and the light rays whatever I send it is gets deflected. And it forms a particular pattern on the speed. Now, you relate what causes the deviation of that rays, by relating these two you will be in a position to find out what cause this change and hence the level of stress concentration. So that is the basic principle behind it.

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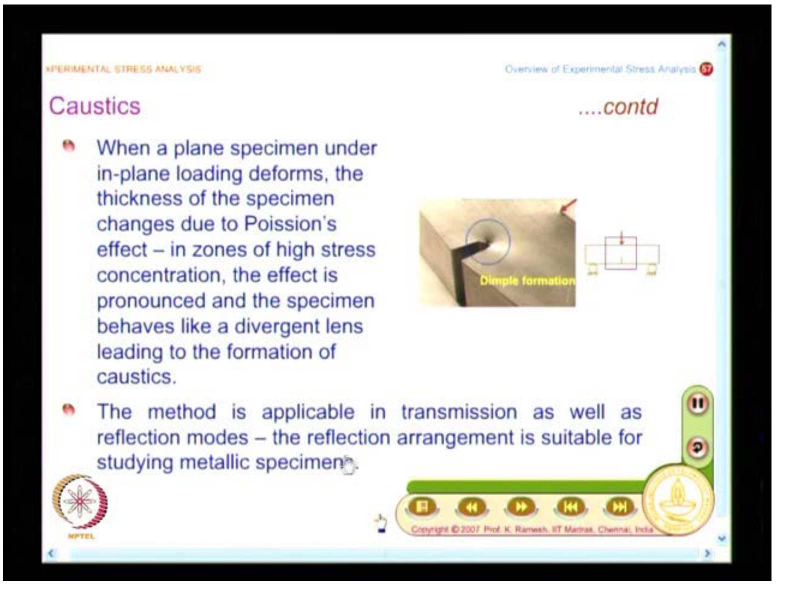

As I mentioned earlier it is applicable to transmission as well as reflection modes - the reflection arrangement is suitable for studying metallic specimens. This also I have said that you need to have techniques to find out for models as well as prototypes, photoelasticity has transmission photoelasticity and deflection photoelasticity. So, in method of caustics you can do it on transparent models as well as on opaque - metallic specimens. And particular in fracture mechanics when people wanted to understand the plastic deformation at the crack tip caustic really helped and it really helped for people who know little bit of fracture mechanics establishing the concept of HRR field- Hutchinson-Rice-Rosengren field near the crack tip was very well established with the method of caustics. And what I will do is I will elaborate this, this aspect of the specimen becoming a divergent lens, we will have a look at it and this I am going to the chapter on caustics.

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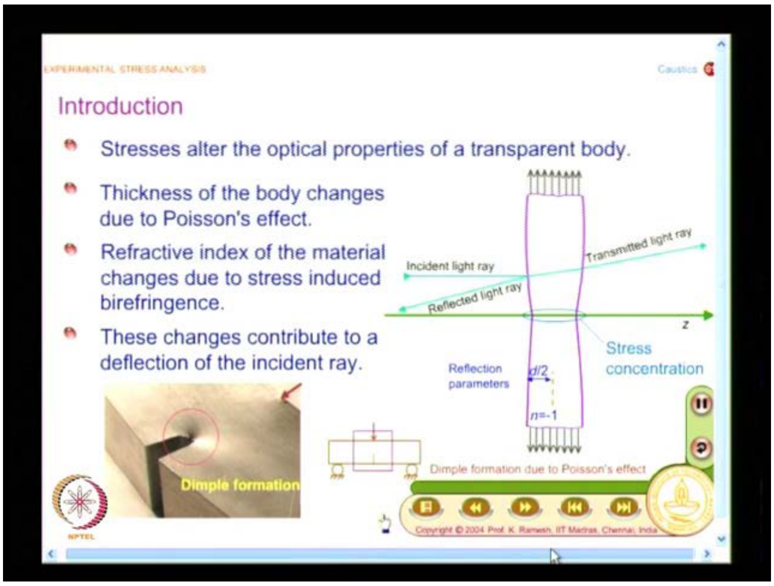

I will just show you how this deformation is recorded. So, this is the specimen I have, I have a stress concentration here, I pull this model and from this from this you know it is exaggerated that you see a thickness change very prominently noted near the stress concentration. Stresses alter the optical properties of a transparent body; you will also have change in the refractive index. If it is a metallic specimen, there is no question of refractive index getting changed. In the thickness change because of Poisson effect is very prominent near the stress concentration zone. And if I use the transparent model most of the transparent models which we use also birefringent. So, the refractive index also has an influence. So, the combined influence of these causes the formation of caustics. So, what is see here is I have an incident ray and it get transmitted, it does not go straight it gets deflected it gets deflected.

And because of these changes when I send a beam of light I will get a shadow essentially behind the specimen in transmission arrangement and on the reflected this one you will see on this plane. And you have certain parameters, you do not at worry about than now, when you go into mathematical development which may be may not do in this first level course. So, you have to take those parameters appropriately. And here again you have shown, for a transmission arrangement this is very clear, for the reflection arrangement you have this dimple very prominently seen. So, when a send the ray will you get reflected light (( )), and because of this you will have a family of rays emerging and that forms a shadow. And if possible I will also illustrated by a simple experiment, but before we going to the experiment, we will also see take a specimen with crack, and make a very simple sketch of it, and look at what happens. I will just show that animation for a minute then we move on to the experiment.

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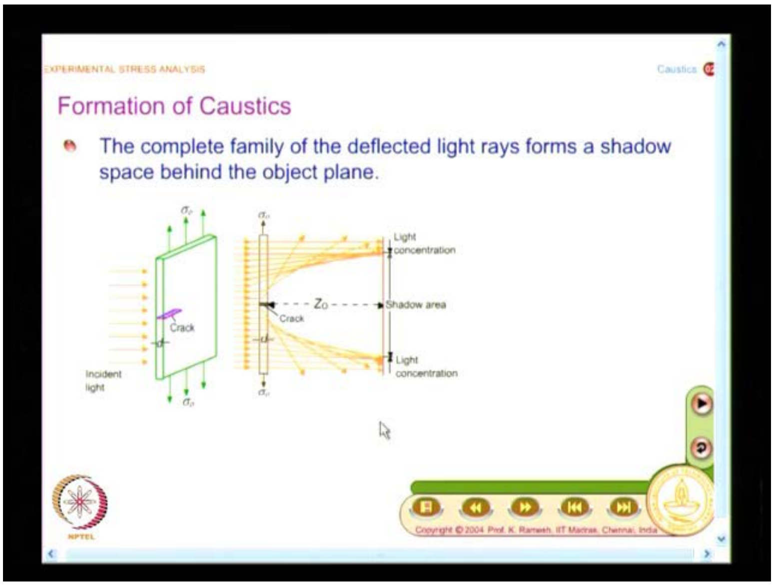

And this ex this is very formation of caustics is very clear; just observed the specimen. So, what I have here is I have a specimen with a crack, I have parallel beam of light impinging on the specimen, and because of the Poisson ratio effect the light does not go straight. If I do not load the model, the light will go straight and light gets deflected like this. And because this gets deflected, you get a shadow region on this screen, and you have reinforcement of these rays form a silver line enclosed in the shadow line. Because that is found becomes of the principle of caustics, you call the entire methodology as method of caustics; we derives the name from that. So, you have a family of rays which reinforce and give you a silver line. Is the idea clear? And what we will do is you can actually illustrate caustic by a very simple experiment even in the lecture class.

And what I have here is I have a I have a polyurethane specimen, because this I can stretch easily and I have a crack, I do not think it is very clear the may be I will put a white background, I will put a white background you are able to see the you are able to see the crack here you are able to see the crack here and I do not whether the camera is good enough to show the… If I stretch it I will see a dimple that is getting formed. I will get a dimple being formed at the crack tip. Even visually you can see even visually you can see, you can have a dimple formed at the crack tip and I pull it you will see the dimple, and if you are not able to see the dimple we will see, we will send a laser beam of light and then find out what happens. So, what we will do is, can I have one person come and help me.

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So, what I have here is I have the model here, and I will send the laser beam of light it is not loaded, I see that has a point, it is load this specimen. And you will find that the rays are getting deflected the rays are getting deflected. The rays are not going, because I am just doing it with hand I am not able to show you the shadow completely. But this is what happens. We are able to see that the rays are not going straight, but that they get deflected. And if you come here, if you look at the sketch again, what you have here is you have this stress concentration and rays get deflected. And if you actually perform the experiment you will get the shadow like this; we will have a look at a (( )) moment I will show you this.

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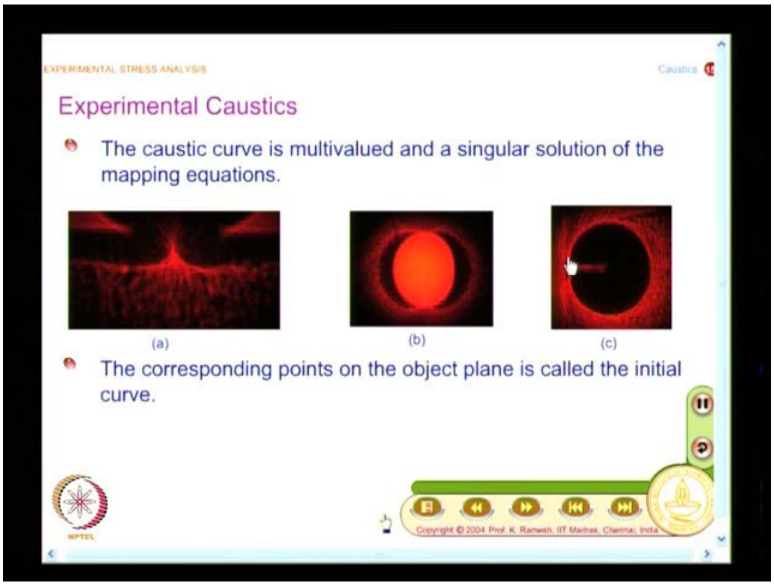

And this is a caustic is shown for different problems of stress concentration. It is a semi infinite plate with a concentrated load. This is a plate with a hole, you have a figure of 8 and this is a plate with a crack. I have the crack here and I have a caustic envelope like this. So, you have a shadow bound by a silver region. And you can see very clearly I have a shadow; this is bound by a silver region that what you have. And this is the caustic shadow for a mode one crack.

So, you send a beam of light you get a shadow; you do not get light pass through and there is mainly because you have the specimen behaved in a fashion where you have thickness change. So, the light whatever the light rays impinged on it, it diverged; it behave like a divergent lens. And you do not have a light here and that becomes shadow and that is what you see in the screen. And this is what I try to show and in fact, you can do it (( )) very carefully will be able to see it, your hands are shaking you are not able to see that in the glass and… So, it is a very interesting phenomena. So, what will have to keep in mind is if people find out the physics they are waiting to exploit and developing (( )). And this has found very good application the early development of fracture mechanics to establish HRR field, this was a very ideal technique. And…

So, in this class what we have looked at is we have looked at we continue our discussion on speckle interferometry, we saw what is shearography, then we moved on to thermoelastic stress analysis. I caution that you should not interpret that this is meant for finding out stresses due to thermal loading. You it exploits the temperature change and finds out the information of variation of sums of principle stress. When we looked at image correlation I said it is one of the very nice emerging techniques. It is also becoming a general purpose tool like strain gauges and photoelasticity.

As of now the equipments are little expensive and also this software is proprietary in nature, people have developed their own software, they are becoming cost effective. Then we also saw very interesting aspect of how caustics is employed to reveal high stress gradient information, it is not a general purpose tool. If you use image correlation it is a general purpose tool, if you use photoelasticity it is a general purpose tool, if you use strain gauges that is also a general purpose tool. The moment you come to caustics it is particularly sensitive to high stress gradient information. And I have shown the caustic shadow for three problems; one is for the semi infinite plate with a concentrated load, plate with a hole and the third one is plate with a crack stretched. Thank you.